
Reliable, Low Cost Distributed Generator/Utility System Interconnect

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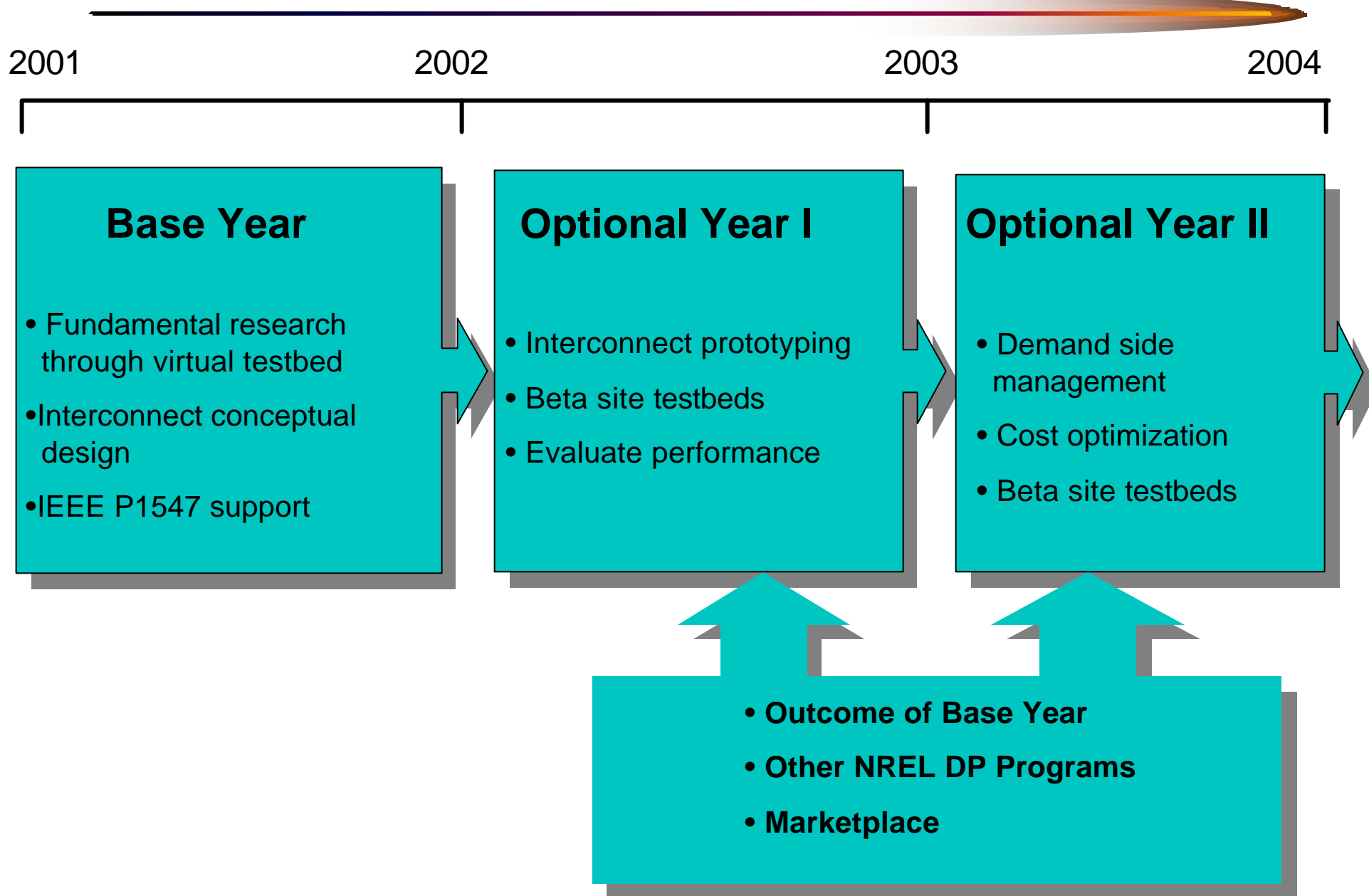
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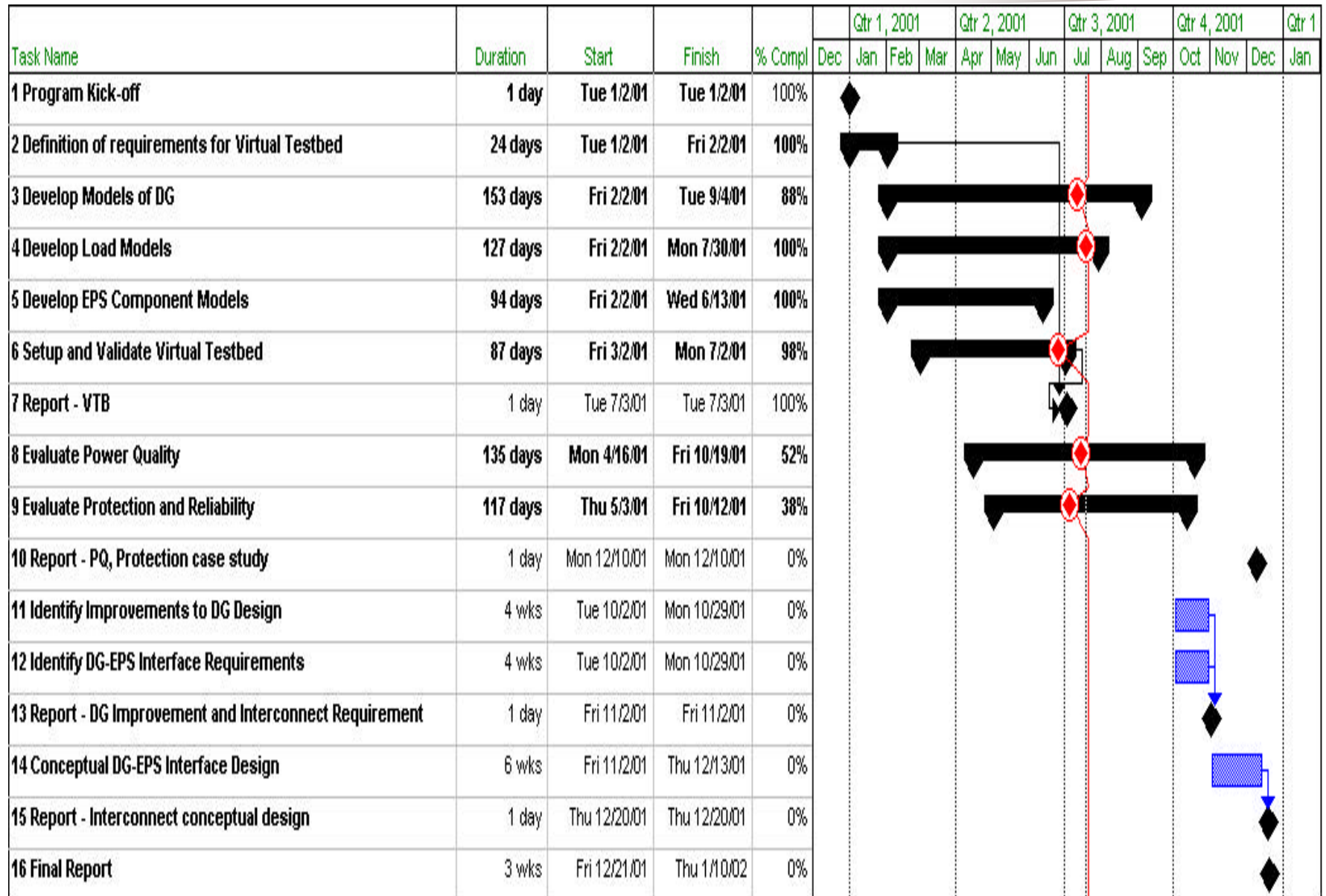


Puget Sound Energy

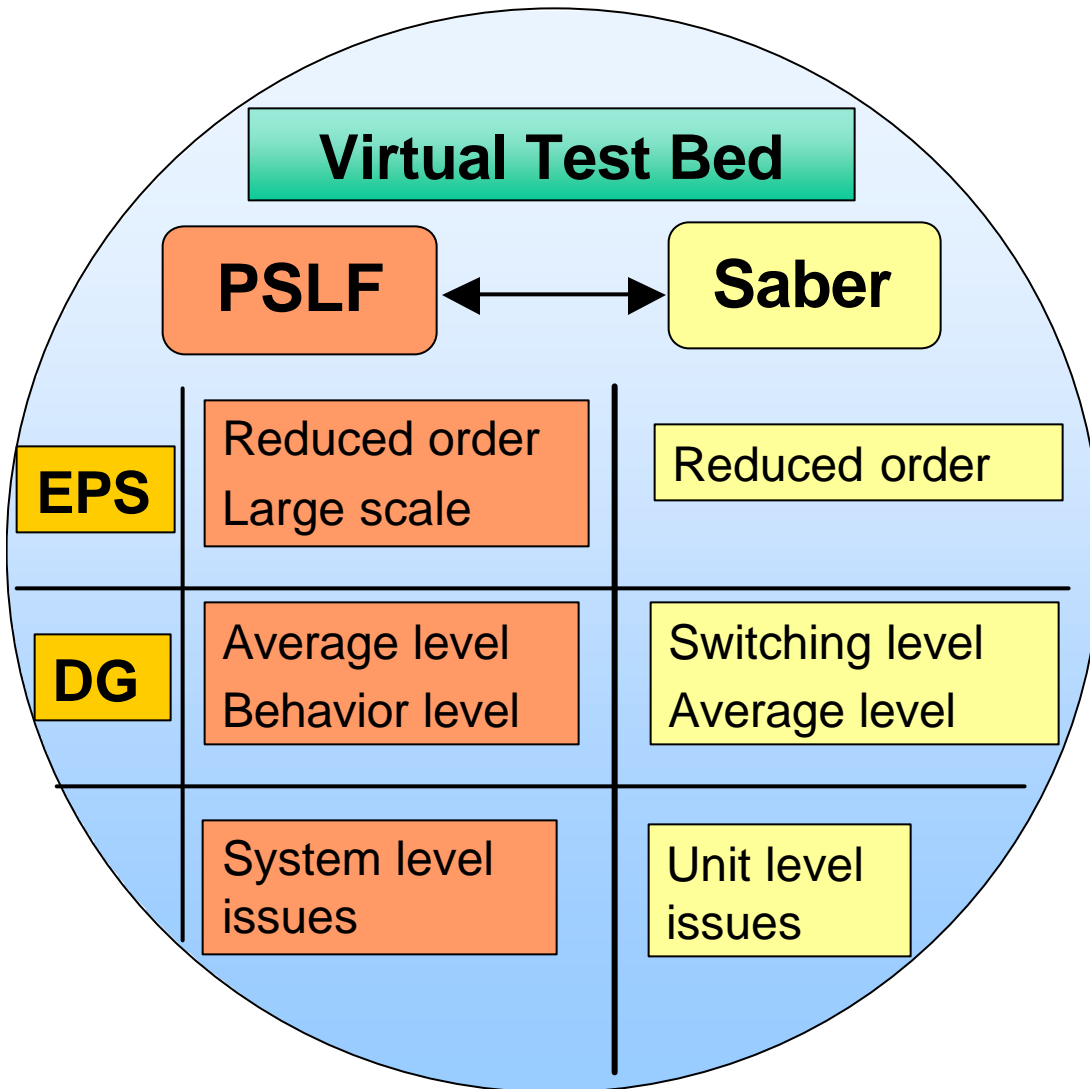
Program Structure



Base Year Schedule



Virtual Test Bed - Structure



Why PSLF and Saber?

•PSLF - commercially available modeling tool for analyzing large system response

- “Fundamental Frequency Program”
- Power grid modeled algebraically

$$\tilde{V} = \tilde{I} (R + j(X_L + X_C))$$
- < 5 Hz modulation bandwidth
- Electromechanical oscillations and some controls modeled dynamically
- Handles very large systems

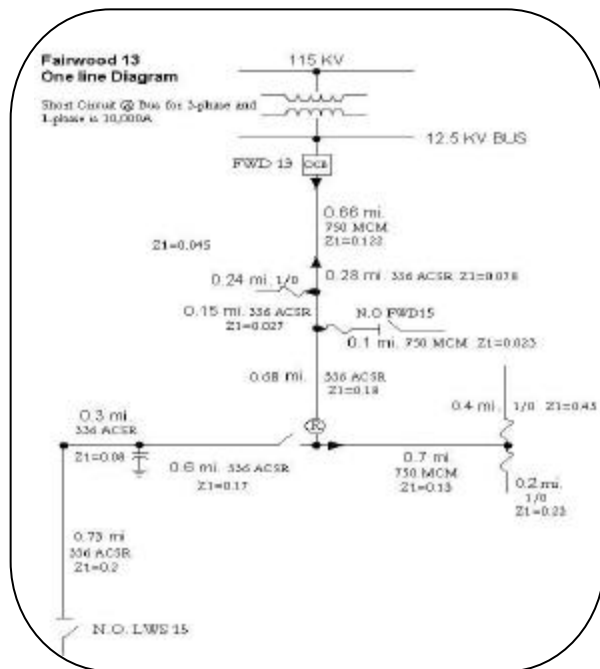
•Saber - powerful system modeling tools for mixed technologies

- Detailed transient simulation
- Entire system modeled by differential equations

$$V = R I + L \frac{dI}{dt} + C \int I dt$$
- Unlimited bandwidth

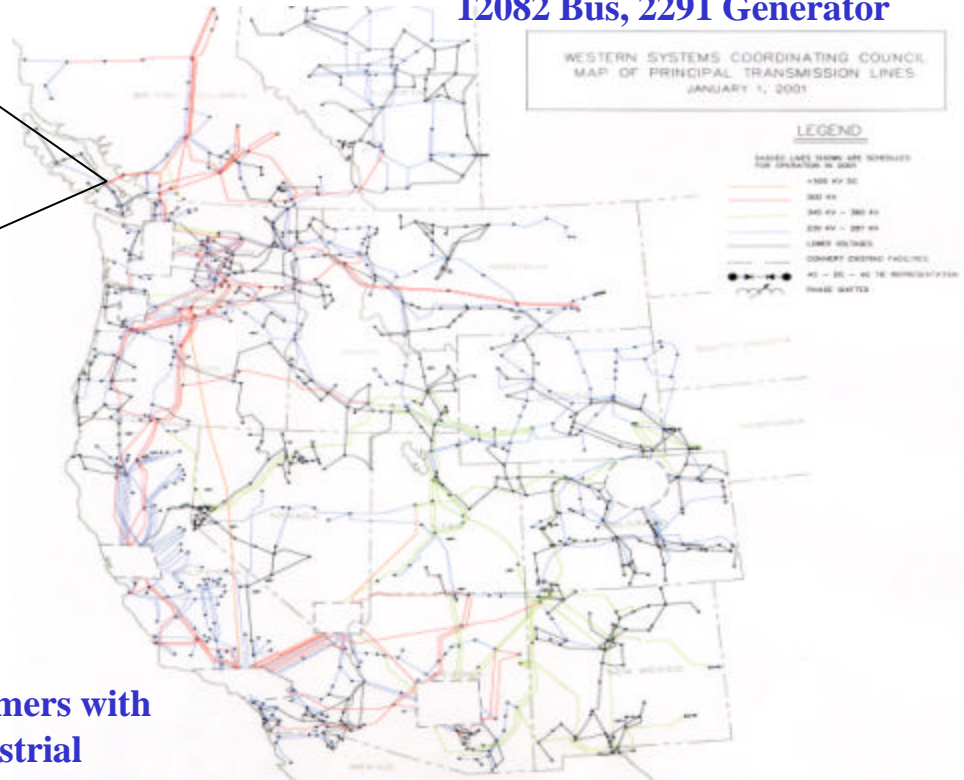
Virtual Test Bed - PSLF Setup

- P1: PSE 12.5kV Feeder. Approx 1200 customers; mixed residential, commercial, light industrial. Candidate for beta test site.
- P2: Representative, but fictional system with 2 feeders, which can be looped. Explicit representation of 5 candidate DR locations, including transformers.
- P3: WSCC - 12082 bus, 2291 generator model

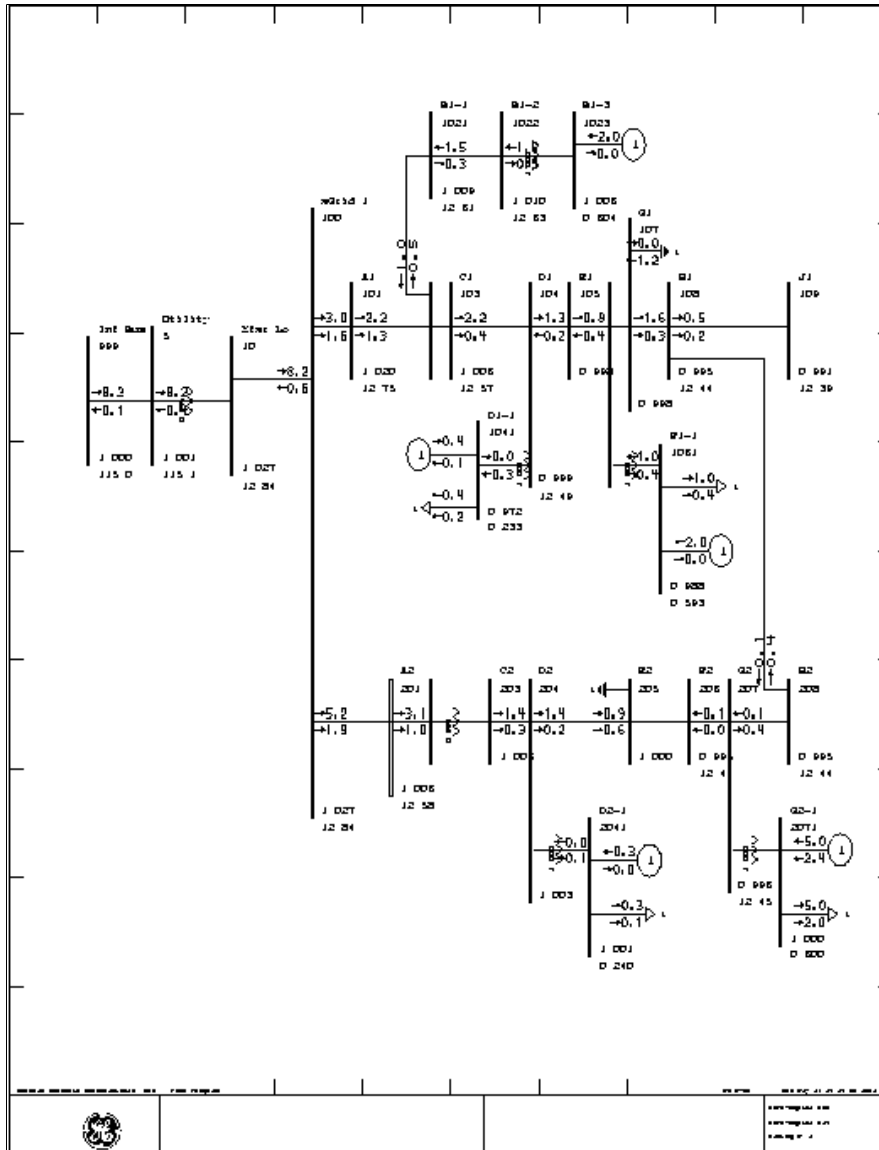


Fairwood System Modeled in PSLF (P1)
PSE 12.5kV Feeder; Approx. 1200 customers with mixed residential, commercial, light industrial

WSCC System Modeled in PSLF (P3)
12082 Bus, 2291 Generator



Virtual Test Bed - PSLF Setup



Representative Distribution System Modeled in PSLF (P2):

- Two 12.5kV Mains
 - 28 node equivalent, including laterals
 - 240v and 600v secondaries with transformers represented
 - Substation LTC
 - 1200 kVar Shunt bank on #1
 - SVR on Feeder 2
- 13,700 kW Load
 - 2831 kW pumps
 - 6467 kW other motors
 - 4371 kW static load
 - 36 dynamic models
- 6405 kW Distributed Generation
 - 5 equivalents, with dynamic models
 - 2 units with voltage and power regulation functions

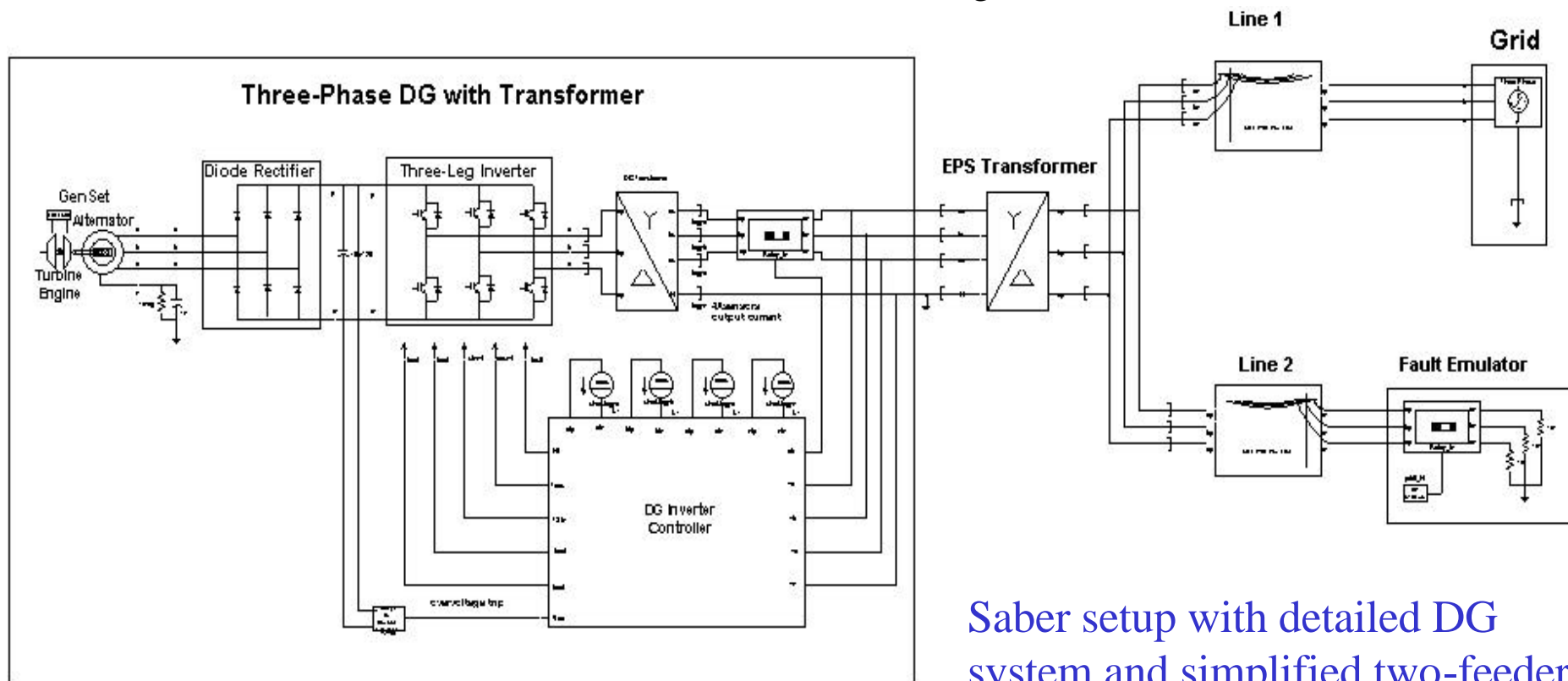
Virtual Test Bed - Saber Setup

Saber

S1: Simplified inverter based DG and single feeder EPS.

S2: Medium complexity inverter based DG with local distribution

S3: Full-order inverter based DG with PWM switching function



Saber setup with detailed DG system and simplified two-feeder distribution system

Virtual Test Bed - Model List

DG Models

- synchronous machine
- induction machine
- single and three-phase inverter

EPS models

- overhead line/cable
- circuit breaker
- surge arrestor
- fuse
- recloser
- transformer
- saturable inductor
- sectionalizer
- fault emulator

DG/EPS Building Blocks

- anti-islanding algorithms
- phase-lock loop
- over/under voltage relay
- over/under frequency relay
- over current relay
- impedance relay
- reverse power relay

Load Models

- cycle skipper
- phase-controlled load
- sump pump

The models are implemented at three complexity levels

Basis for Case Studies

- Explore how systems work and identify systems issues

Steady-State Performance

- Voltage Profiles and Impacts
- Voltage Regulation
- Current and Thermal Impacts

Fundamental Frequency Dynamic Performance

- First Swing Stability Performance
- Monotonic Frequency and Voltage Impacts
- System Oscillations and Damping
- Flicker

Power Quality

- Grid stability
- DG reactive power control
- Unbalanced grid
- Harmonics
- Flicker
- DG Paralleling transient

Protection and Reliability

- Fault Behavior
- Anti-islanding protection
- Recloser Interactions
- Relay and Fuse Coordination
- Grounding

- Determine the impact of the utility connection on the design of DG power electronics.
- Determine the impact to the utility network of increased DG penetration.

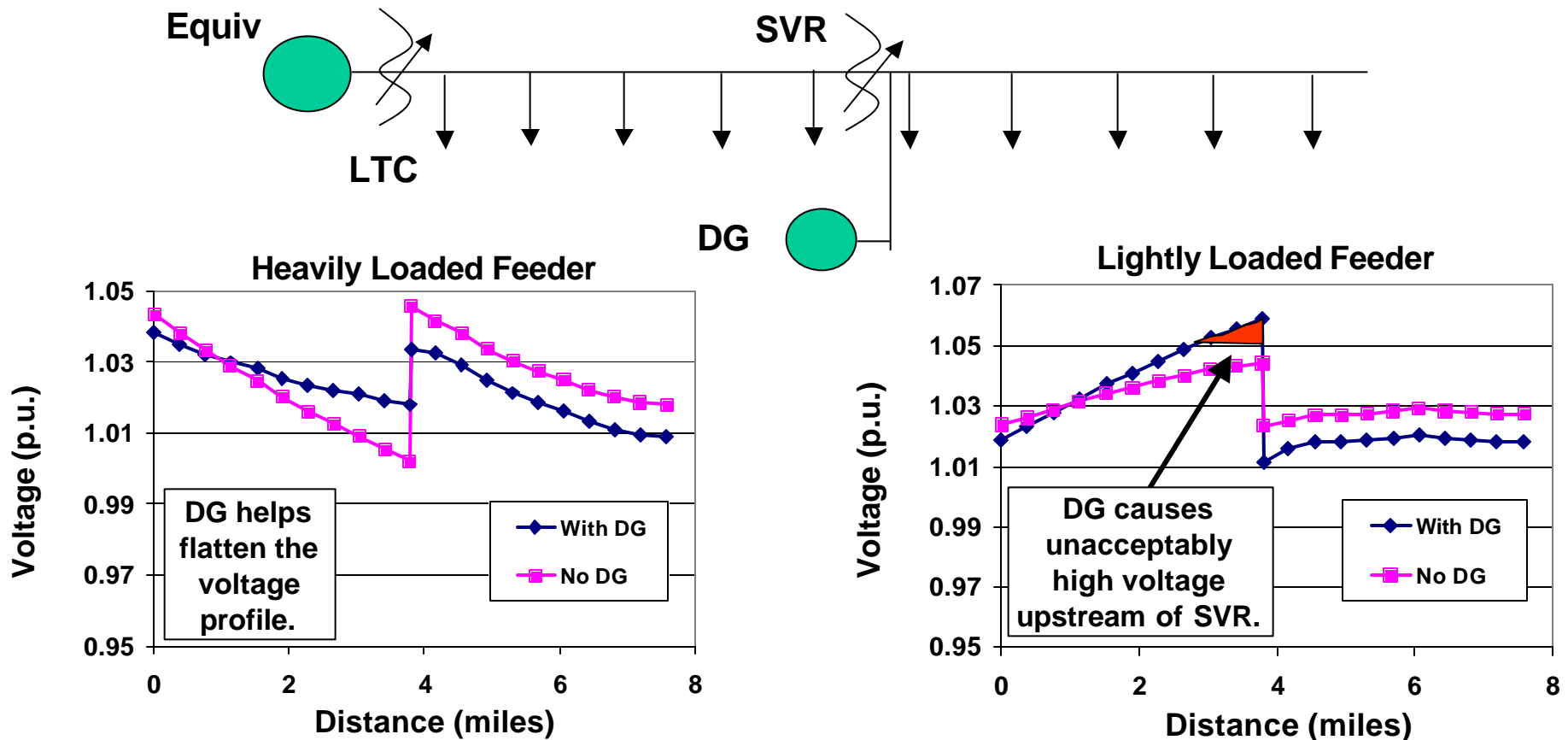
Steady State Performance Example

Investigations/Parameter variations made on the Radial Study Feeder

- Penetration
- DG placement
- Regulator and LTC parameters and control
- Cap bank placement and control
- Voltage regulation by DG

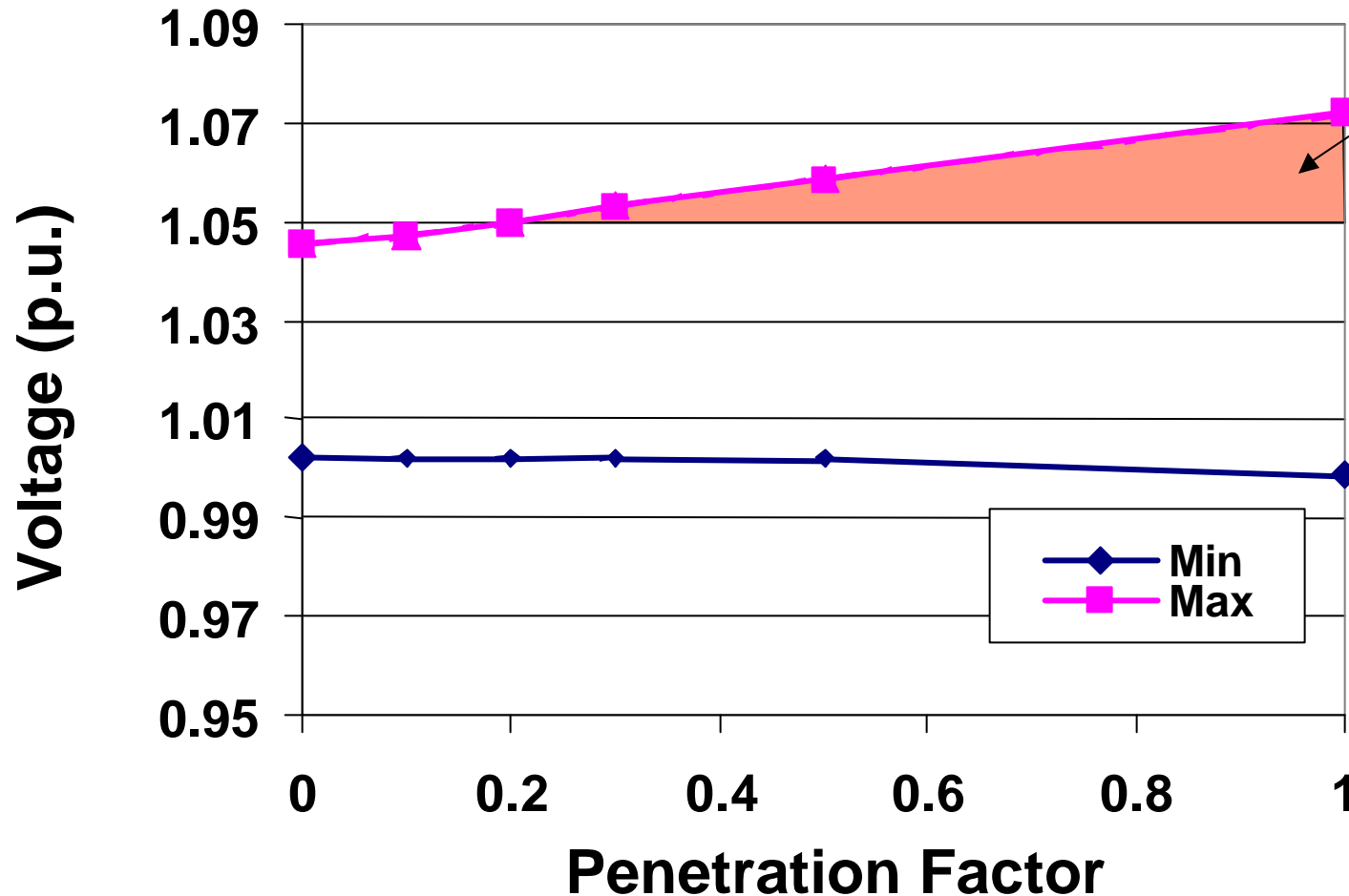
Characteristics of the Radial Study Feeder

- The DG provides 50% of the rated load of the feeder.
- The load is uniformly distributed along the feeder
- There is an SVR at the mid-point, just upstream of the DG.
- The SVR regulates the downstream voltage.
- The LTC regulates the substation bus.



Steady State Performance Example

Maximum and Minimum Voltage with DG



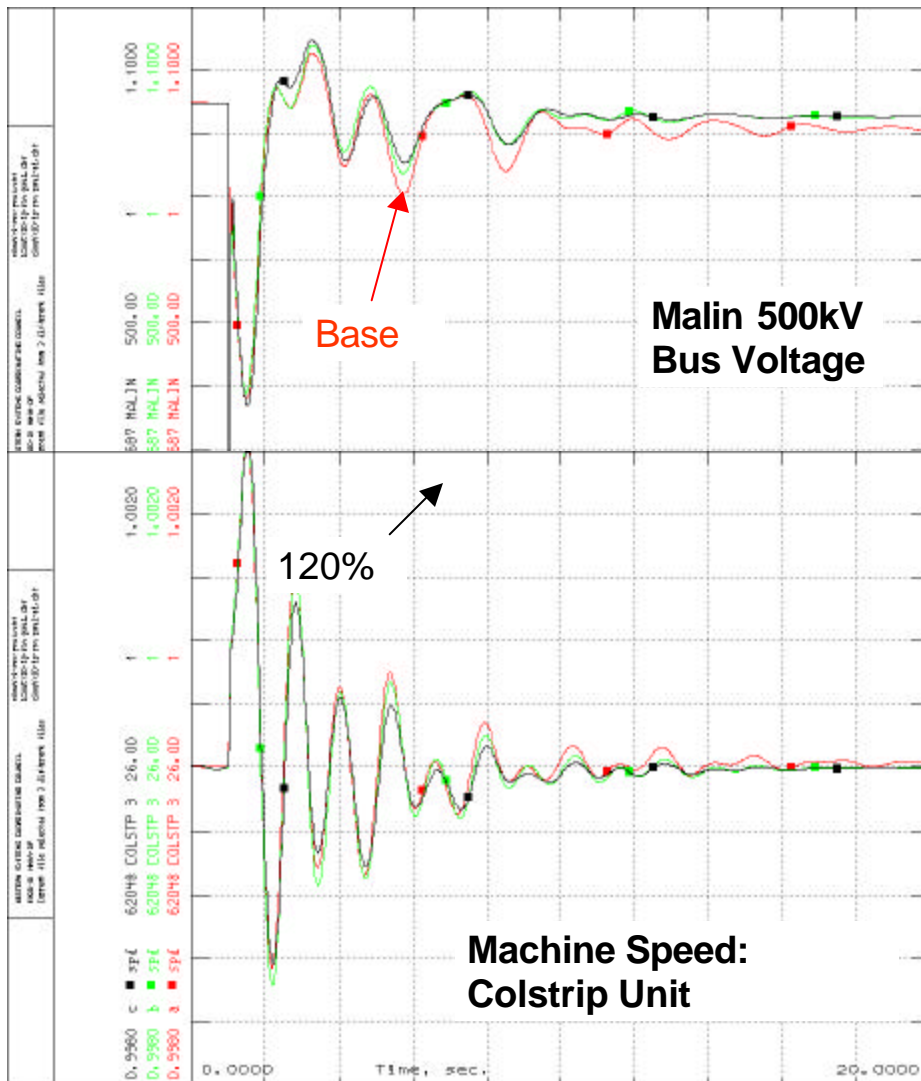
Uncontrolled DG can cause high voltages at light load for significant penetrations

Conditions:

- DG penetration based on full feeder load
- DG can operate anywhere between its minimum and maximum rating
- Locus is for all load conditions from light (30%) to peak (100%)

Fundamental Frequency Dynamics Example

WSCC System response to a large disturbance



Conditions:

- Heavy Winter 2001 Load Level
- Fault at Raver
- Cleared in primary time by trip of 500kV line to Paul

Key:

Red: Base condition

Green: Load uniformly increased by 20% served by equal amount of inverter based DGs with constant power control

Black: DGs with one anti-islanding scheme

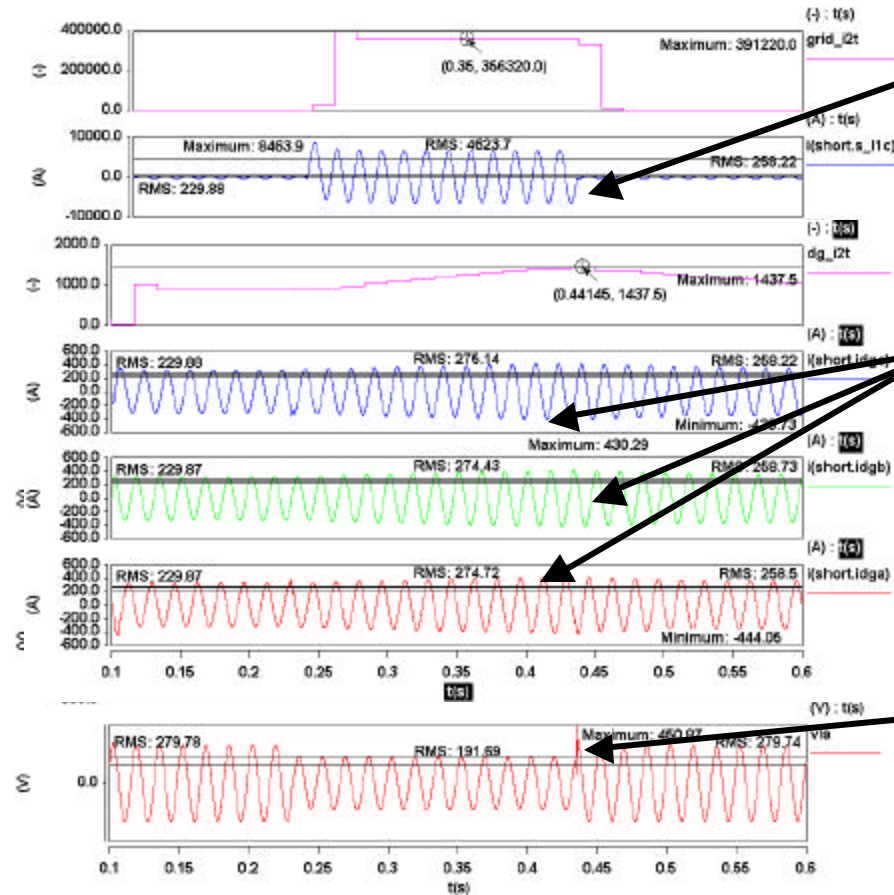
Impact of widespread DG at the loads is benign and slightly beneficial...

However, aggressive trip characteristics could pose a system risk

Fault Performance Example

Three phase short circuit on downstream load

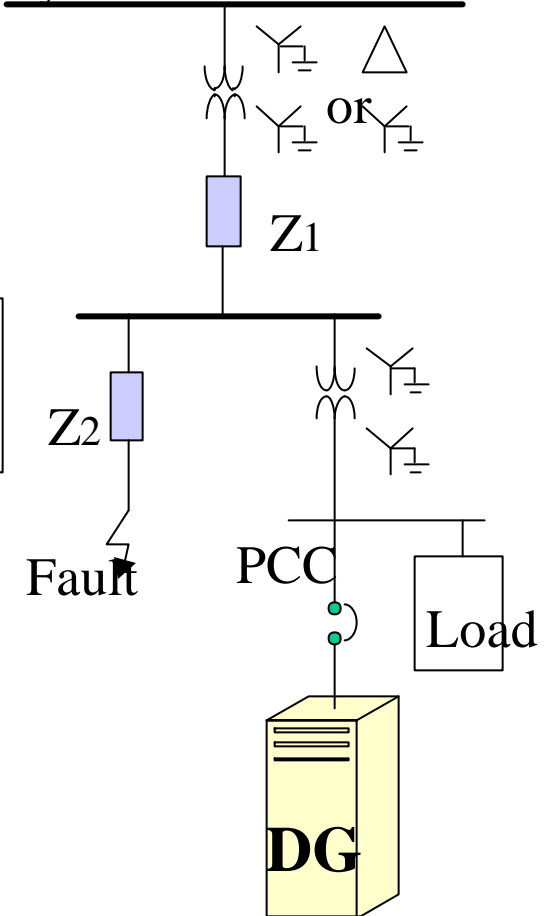
Primary Distribution Feeder



Grid contributes to fault I^2t

Minimal impact on DG output current as it responds as a current source

Voltage dip at PCC depends on fault and line impedance



Inverter based DG impact on overcurrent protection appears minimal

Key Findings from Case Studies

(What have we learned so far?, What's interesting?)

- **Power Quality**

- Modest penetration of DG has relatively little effect on system voltage regulation.
- High penetrations add challenges for voltage regulation, and may require additional controls/intelligence/communication
- Large scale penetration of DGs at the load appear to be benign with respect to bulk system dynamic performance

- **Protection and Reliability**

- Inverter based DG systems act essentially as ideal current sources. Therefore minimal fault current contributions, have little effect on overcurrent protection
- DGs designed with overly aggressive trip characteristics pose a system risk
- Active anti-islanding schemes in distribution systems with multiple DGs and significant motor loads appear to work well

Wrap-Up



TASKS

COMPLETION DATE

- | | |
|--|---------------|
| • Complete the fundamental research (power quality, protection and reliability) of DGs using VTB | October 2001 |
| • Identify improvements in DG design and requirements for DG-EPS interface | October 2001 |
| • Develop a conceptual hardware design for DG-EPS interface module | December 2001 |
| • Participation in IEEE P1547 | Ongoing |



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